SCHOOL OF
CIVIL ENGINEERING

INDIANA
DEPARTMENT OF HIGHWAYS

JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-85/14

Executive Summary

THE USE OF FUZZY SETS MATHEMATICS TO ASSIST PAVEMENT EVALUATION AND MANAGEMENT

M. Andonyadis
A. G. Altschaeffl
J. L. Chameau

PURDUE UNIVERSITY

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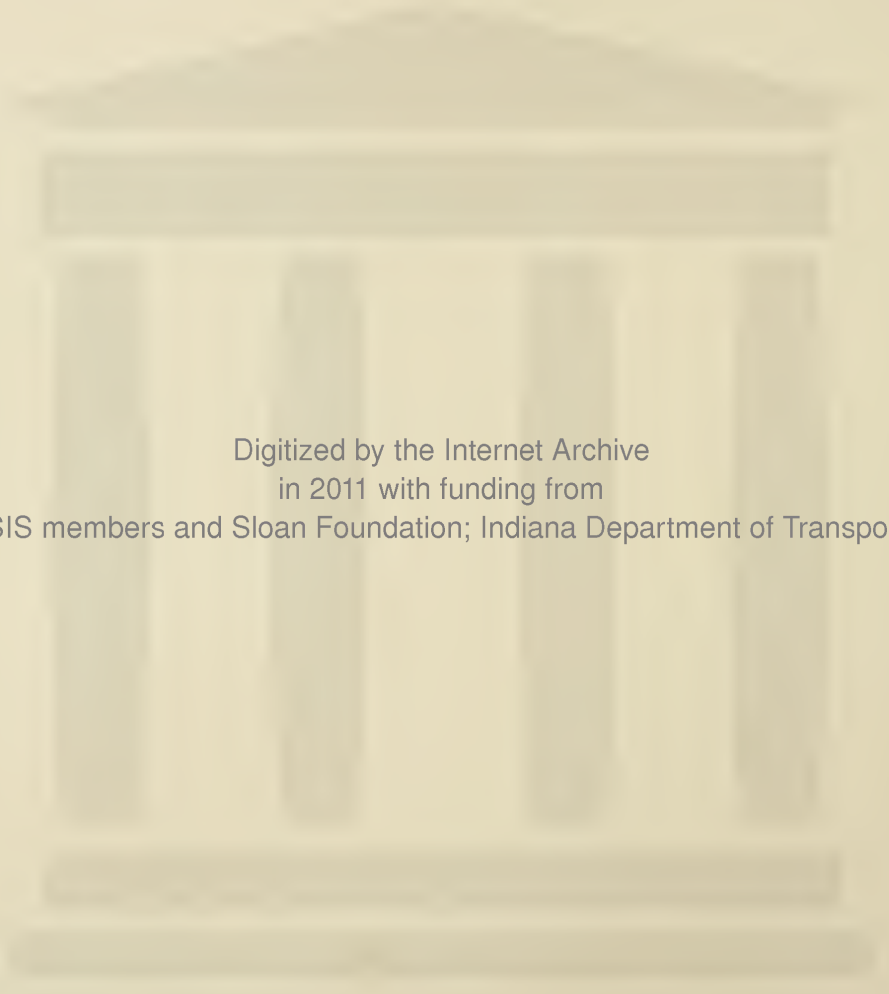

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EXECUTIVE SUMMARY

Final Report

"Use of Fuzzy Sets Mathematics to Assist
Pavement Evaluation and Management"

To: Harold L. Michael, Director
Joint Highway Research Project

July 2, 1985
revised March 18, 1986

From: A. G. Altschaeffl, P.E.
Research Engineer
and J. L. Chameau,
Research Associate

Project: C-36-63J

File: 9-7-10

Please find attached the Final Report on the HPR Part II Study entitled, "The Use of Fuzzy Sets Mathematics to Assist Pavement Evaluation and Management". Its authors are Mr. M. Andonyadis, A. G. Altschaeffl, and J. L. Chameau of our staff.

This report implements and applies the mathematics of fuzzy sets to the performance data for IDOH pavements. In doing this, the report represents the fulfillment of the objectives of this study. It is companion to the interim report of Gunaratne, et al. (1984), which created the mathematics.

The new scheme being suggested for pavement management is predicated upon the thesis that uncertainty is present and judgment must be applied at various stages of pavement management. The fuzzy sets mathematics can methodically combine subjective information and crisp measurement data.

The ranking of pavements is formulated using fuzzy multi-attribute decision-making concepts. To use the new scheme required the one-time development of a knowledge base. At any time thereafter, performance data can be applied to the knowledge base to develop a crisp rank-ordering of pavements according to their maintenance urgency. This report presents the details of the development of the knowledge base using responses from experts to appropriate questionnaires.

Included within this report are suggestions for improvement in the Indiana pavement management program, which could take full advantage of the possibilities offered by this new scheme.

This Final Report is submitted for review and approval as fulfillment of the objectives of this Study.

Respectfully submitted,

A. G. Altschaeffl, P.E.
Research Engineer

J. L. Chameau
Research Associate

EXECUTIVE SUMMARY

Final Report

"The Use of Fuzzy Sets Mathematics in Pavement Evaluation and Management"

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Joint Highway Research Project

Project No.: C-36-63J

File No.: 9-7-10

Prepared as Part of an Investigation

Conducted by

Joint Highway Research Project
Engineering Experiment Station
Purdue University

in cooperation with the

Indiana Department of Highways

and

Federal Highway Administration
U.S. Department of Transportation

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data reported herein. The contents do not necessarily reflect the official views in policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Purdue University
West Lafayette, Indiana

July 2, 1985
revised March 18, 1986

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/IN/JHRP-85/14		

4. Title and Subtitle	5. Report Date
EXECUTIVE SUMMARY "The Use of Fuzzy Sets Mathematics to Assist Pavement Evaluation and Management"	July 2, 1985 revised March 18, 1986
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
M. Andonyadis, A. G. Altschaeffl, J. L. Chameau	JHRP-85-14

9. Performing Organization Name and Address	10. Work Unit No.
Joint Highway Research Project Civil Engineering Building Purdue University West Lafayette, IN 47907	11. Contract or Grant No. HPR-1(23) , Part II
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address Indiana Department of Highways State Office Building 100 North Senate Avenue Indianapolis, IN 46204	FINAL REPORT
	14. Sponsoring Agency Code

15. Supplementary Notes

Conducted in cooperation with U.S. Department of Transportation, Federal Highway Administration, under a research study entitled, "The Use of Fuzzy Sets Mathematics to Assist Pavement Evaluation and Management".

16. Abstract

This report applies the mathematics of fuzzy sets that was created in the companion Interim Report by Gunaratne, et al. (FHWA/IN/JHRP-84/18).

The new scheme being suggested for pavement management is predicated on the presence of uncertainty at various stages in pavement management which requires that judgment be used in the process. The fuzzy sets mathematics can methodically combine subjective information and crisp measurement data. Fuzzy sets are used to represent the subjectivity in pavement serviceability ratings and distress surveys, and the variability in Roadmeter, Skid-Tester and Dynaflect readings.

The ranking of pavements is formulated using fuzzy multi-attribute decision-making concepts using an expert knowledge base. To use the new scheme required the one-time development of the knowledge base. Any time thereafter, performance data can be applied to develop a crisp rank-ordering of pavements according to their maintenance urgency. This report presents details of the development of the knowledge base using responses from experts to appropriate questionnaires.

Suggestions are also included for improvements in the pavement management program to take full advantage of the possibilities offered by this new scheme.

17. Key Words	18. Distribution Statement
Fuzzy sets mathematics; pavement evaluation; pavement management; PSR; PSI; Roadmeter; Skid Tester; Dynaflect; multi-attribute decision-making	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	6	

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EXECUTIVE SUMMARY

Introduction

This is the Final Report for this project. There were 4 objectives established for the project in pavement evaluation and management. These objectives were: (1) To establish what is possible with the fuzzy sets mathematics in this area; (2) To develop and use subjective judgment in pavement performance evaluation; (3) To develop procedures to combine subjective judgment data and measurement data to establish maintenance priorities for pavements with unacceptable PSI; (4) To develop procedures to establish maintenance priorities for pavements with unacceptable skid or deflection characteristics.

The objectives have been fulfilled in 2 reports. The first, by Gunaratne et al. (1985), presented the procedures to be used and their mathematical justifications. It described the techniques which can be used for the initial screening of pavement sections and for their subsequent priority ranking. This interim report had three goals:

1. To describe the mathematical techniques used in both the initial screening and the decision process;
2. To develop the framework (set of questionnaires) which can be used to acquire the expert knowledge base;
3. To provide simple numerical examples of application of the mathematical techniques.

The second report, which serves as the Final Report of the project, applies the proposed techniques. It presents the details of the new scheme being suggested for pavement management, including simple physical interpretations of the mathematical techniques. To use the scheme requires the one-time development of a knowledge base. This report describes the details of the development

of the knowledge base using responses from experts to appropriate questionnaires. Computer programs are presented to facilitate the assembly and future use of the information.

To create maintenance priorities requires the application of performance data to the knowledge base. This was done for a recent set of IDOH data. The report presents the details of this application which results in a crisp ranking of priorities. There are also included several suggestions for improvement in the pavement management program which should be considered in order to take fuller advantage of the possibilities offered by the new scheme.

This final report follows the framework proposed by Gunaratne et al. (1984) for the use of fuzzy sets in pavement evaluation of management. It describes how the mathematical techniques can be used in the pavement management system. It has four goals:

1. To provide simple physical interpretations of the mathematical techniques;
2. To use questionnaires to acquire a typical knowledge base;
3. To show in selected examples how the knowledge base can be used to screen and prioritize pavement sections;
4. To make recommendations for future implementation of the proposed management system.

In this context, the following sections of this summary highlight the important steps of the methodology proposed in this report. The reader who is interested in the theoretical concepts and mathematical models used in the proposed approach can refer to the interim report by Gunaratne et al. (1985). The final report is intended to stand by itself, although the reader may also want to read the executive summary written for the interim report. This earlier executive summary outlined the general concepts which guided the investigators in their work.

Knowledge base

The knowledge base consists of the following elements:

a) Variation in parameters: The measured RR values were represented by fuzzy sets. Variations due to irrepeatability, climatic and vehicle speed changes were modeled by attaching a range of variation to the measured RR number.

Friction numbers of the pavement sections were also expressed as fuzzy sets. Climatic and vehicle speed changes were modeled by introducing ranges of variation.

At present, the IDOH does not use Deflection numbers at any stage of the decision making for prioritizing the pavements. This parameter is only used as undersealing criterion. Therefore, there was not enough deflection data available to include this parameter in the evaluation as was proposed by Gunaratne et al. (1984).

Fuzzy sets were introduced in distress surveys, since human based uncertainty affects evaluation of the different kinds of distress.

b) PSR-RR relationship: The PSR-RR relationship (matrix) was formed using the data supplied by the IDOH Research and Training Center. This data was related to a limited number of pavement sections and was not sufficient to completely determine the PSR-RR matrix. Two alternate techniques were developed to overcome this problem.

c) Acceptable levels of PSI and FN: Acceptable serviceability and skid resistance levels were obtained from the responses provided by experts. Since there is no clear demarcation line between acceptability and nonacceptability levels, a transition zone was used in this study as guided by the experts' responses.

d) Utility Values: Utility values were provided by experts for a number of selected combinations of attribute values, covering a wide range of those

attributes. This was done for each of the three categories of pavements. Using this information and a point by point polynomial interpolation, the corresponding fuzzy utilities can be obtained for any combination of attribute values. These attributes were: Friction Number, Pavement COndition Rating, and Average Daily Traffic for pavements in the first category (nonacceptable skid resistance); Pavement Serviceability Index, Pavement Condition Rating, and Average Daily Traffic (ADT) for pavements in the second category (nonacceptable roughness); and PSI and Friction Lives as attributes for the pavements in the third category.

Application of the method

The first step in the proposed method is to gather the following data: Annual Daily Traffic, Roadmeter Reading, and Friction Number for the pavement sections that are going to be ranked. The Pavement Condition Rating is not necessary for pavement sections that have acceptable roughness and skid resistance according to the results of the initial screening.

The next step is to fuzzify the RR and FN using the ranges provided by the experts. Then, the PSR-RR knowledge base is entered with the fuzzy RR, and the fuzzy PSI is obtained. The PSI and FN are compared with acceptable and unacceptable levels and the initial screening of the pavements is performed. PCR values are obtained for pavements with nonacceptable roughness and the corresponding fuzzy sets are created. Finally, the pavement sections are ranked with respect to urgency for maintenance, using the utility functions which contain the knowledge base provided by experts. The computer programs necessary for the different stages of the method are developed. The input required from the user consists of performance and traffic data such as RR, FN, PCR and ADT. A typical example of application was given using the data set provided by the IDOH. This particular data set contained a limited number of sections for each pavement type.

The knowledge base required to use the method is formed once. It consists of the PSR-RR relationship, acceptability and nonacceptability levels for PSI and FN, and utility values for a given number of combinations of the attributes affecting the performance of the pavements. The knowledge base can be updated at any time when new data become available.

Conclusions

The use of the new fuzzy sets based methodology for pavement evaluation and maintenance has been demonstrated in this report. The following conclusions can be drawn from the results of this work:

1) The formulation of the fuzzy sets techniques to handle subjectivity and uncertainty has been successful. The techniques generate crisp rankings of pavement sections for maintenance urgency.

2) The existing pavement management system contains fewer decision criteria than can be handled by the fuzzy sets techniques. This is acknowledged by some experts, by their suggestions to include more variables as, e.g. traffic classification data, especially heavier trucks. Any desired criteria for which a consensus exists among the experts can be included in future implementation.

3) The existing data base available for the Indiana road system can not take full advantage of the proposed pavement management system. There are gaps in the data, whose presence was discovered by the manipulations during the study. The developed ranking method will be utilized more effectively if a PCR inventory for pavement sections with nonacceptable roughness becomes available.

4) The knowledge base that has been created can be used to rank any number of pavement sections. The only effort needed is to obtain the relevant performance and traffic data for the pavement sections that need to be ranked.

Recommendations

The following recommendations are suggested for future implementation of the proposed techniques:

a) More responses should be obtained for the questionnaires seeking information about the ranges of variation pertinent to the performance parameters, i.e. Roadmeter Reading, Friction Number, Pavement Condition Rating, etc.

b) Sufficient data points must be used to develop the PSR-RR knowledge base. This can be accomplished by using a panel of raters who will rate a larger number of pavements covering the whole range of roughness, that is, pavements with very poor to very good riding quality.

c) The roadmeter must be recalibrated periodically against the raters' opinions. Therefore new panel ratings should be frequently obtained.

d) Other attributes such as percentage of trucks, accident and maintenance history of the pavement, and rate of deterioration of skid resistance, can be included in the decision making scheme. Expert opinion need to be obtained for different combinations of these attributes.

e) Linguistic terms such as "many accidents" and "high rate of deterioration of skid resistance", can be represented by fuzzy sets if any of the above additional attributes are included in the pavement ranking procedure. Additional information related to the quantification of the linguistic terms should be obtained from the experts.

f) All the computer programs used for the application of the proposed techniques can be modified to be used on a personal computer. In addition, they can be combined into a single program that will use the stored knowledge base, and the input traffic and performance data of the pavement sections in order to evaluate their ranking with respect to maintenance urgency.

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